Active control of sound travelling through a bogie-shrouds-barriers combination

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Introduction

The combination of bogie shrouds and small barriers is a promising method in the abatement of railway noise. In order to reduce the noise transmission through the gap between the bogie shroud (on the train) and the small barrier, the gap should be as small as possible. However, for security reasons the Bahn AG defined a minimum distance between bogie and shroud, through wich the noise travels unhindered and limits the noise reduction of the method. The aim of this project is to develop a method to active reduce the sound travelling through the bogie-shroud barrier interspace.

Theory

Shroud and barrier are modelled as overlapping cylinder segments (two-dimensional) to examine the effects of different positions of the bogie and the barrier, as well as of the acoustic sources. The sound field is separated in 4 horizontal and vertical rigidly terminated regions with the following approaches:

$$
\begin{aligned}
p_1 &= \sum_{n=0}^{N-1} J_{2n}(kr)\{a_n J_{2n}(kr_s) + b_n N_{2n}(kr_s)\}\cos(2n\phi) \\
p_2 &= \sum_{n=0}^{N-1} \{a_n J_{2n}(kr) + b_n N_{2n}(kr)\} J_{2n}(kr_s)\cos(2n\phi) \\
p_3 &= \sum_{n=0}^{N-1} \{c_n J_{2n}(kr) + d_n N_{2n}(kr)\}\cos(2n\phi) \\
p_4 &= \sum_{n=0}^{N-1} e_n H_{2n}^{(2)}(kr)\cos(2n\phi) \qquad (1)
\end{aligned}
$$

where $H_{2n}^{(2)}$ is the Hankel function of the second kind (outward propagating wave) with the order $2n$, the wave number $k = 2\pi/\lambda$, r the radius and ϕ the angle. J_{2n} and N_{2n} are the Bessel function of first and second kind respectively.

The complex numbers a_n, c_n, d_n and e_n represent the unknown amplitudes where b_n is a known number to constitute the primary source which is a line source at the radius r_s and the angle ϕ_s.

$$\left.\frac{\delta(p_1 - p_2)}{k\delta r}\right|_{r=r_s} = Q\delta(\phi - \phi_s) \qquad (2)$$

With N as the number of modes (theoretically infinite), $4N$ unknown variables exist for the combined boundary value problem. The boundary conditions are set to define equal pressure and velocity at the open boundaries between the regions, and zero velocity at the barrier and the bogie-shroud. The secondary sources are approached as velocity specifications for a region on the bogie-shroud or the barrier.

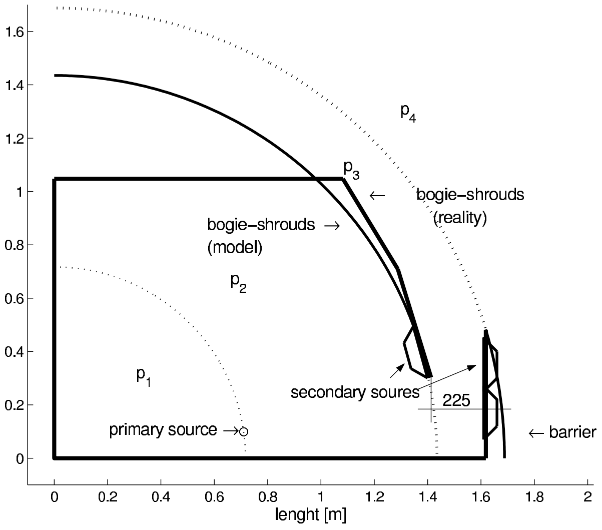

Figure 1: Geometry of the bogie-shroud barrier model. The segments of the circles show the boundaries between the pressure regions. The solid rectangular line shows the profile of the test rig.

The position and the length of the shroud and barrier as well as the position of the sources can be varied. The sound field of the primary and of the secondary source were computed separately and superposed.

$$p_{sum} = p_{passiv} + \alpha p_{active} \qquad (3)$$

where α is the complex amplitude of the secondary source.

Two sets of simulation have been carried out.

- The amplitude and the phase of the secondary sound field were adjusted to minimize the total power output into the far field.
- The secondary sound field was adjusted to establish zero impedance in front of the secondary sources.

Theory Results

The analytical approach shows that the edges of the barrier as well as of the bogie-shroud can be seen as additional sources propagating into the far field.

The calculations show that global diminution of the transmitted power is possible with global control as well

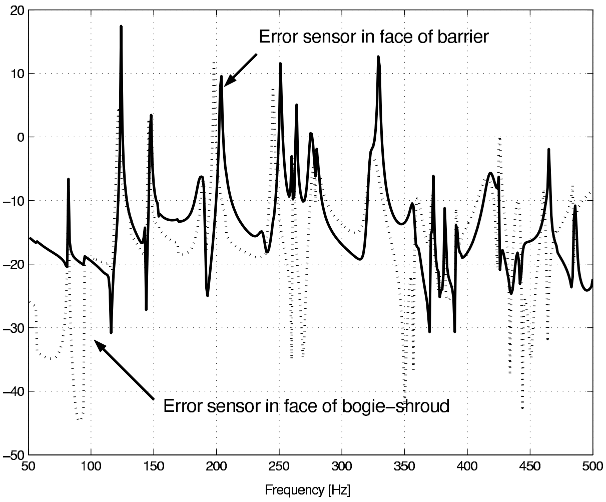

Figure 2: Theoretically possible reduction of the mean squared pressure at reference point (x=2.1m, y=1m), with the secondary source and the reference sensor at the bogie-shroud and the secondary source and the reference sensor at the barrier

as with zeros sound pressure in the region of the secondary source.

A set of calculations were run to optimize the positions of error sensor and secondary source, while keeping in mind that for the practical application error sensors are only possible in the region of the bogie-shroud.

Figure 2 shows two typical results of the calculation on a reference point (x=2.1m, y=1m). Here the error sensors place in front of the secondary sources on the upper edge of the barrier and on the bogie-shroud face to the upper edge of the barrier. The secondary sound field was adjusted to establish zero impedance in front of the secondary sources to produce zero pressure zones. The results show a reduction of the transmitted noise an slight advantage of the secondary source on the bogie-shroud.

From these findings we built a test rig with two sets of secondary sources (which we used separately); one set on the barrier as far as possible towards the upper edge; the second set on the bogie-shroud opposite of the upper edge of the barrier.

Measurements

To validate our theoretical results we started a sets of experiments on an idealistic test rig (see Figure 3). The rig was build of 25mm thick chipboard. Inside of the box we placed an active loudspeaker which acted as the primary source. Two secondary loudspeakers (on the barrier and on the bogie-shroud respectively) act parallel. In this preliminary investigation we worked with sinusoidal (up to 1kHz) and fed the noise signal to the primary source and via FXLMS (see e.g. [1]) to the secondary sources to produce a zeros pressure region around the secondary sources .

We worked with the two sets of secondary sources suggested by theoretical investigation. The global effect of the active control in the acoustic far field we estimated with 6 sensors at a distance of 1m of the barrier, equidistant of 0.25m to 1.50m altitude.

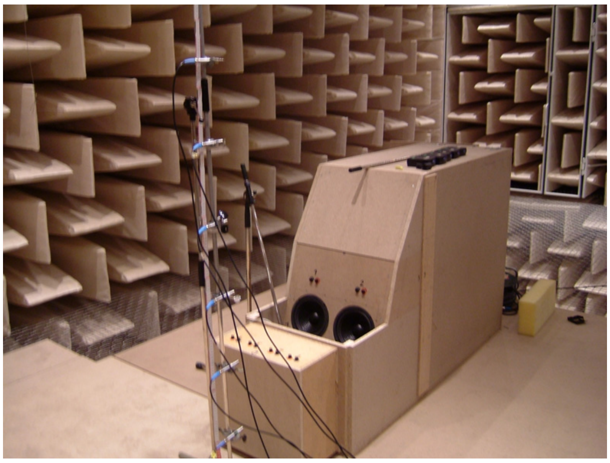

Figure 3: Test rig in the anechoic room of the Institute of Technical Acoustics in Berlin In front the 6 sensors to estimated the far field radiation, two secondary loudspeaker on bogie-shroud with the error sensor in front

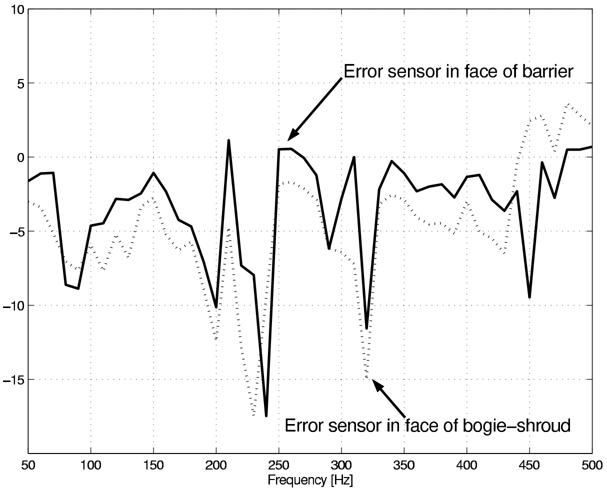

Figure 4: Measured reduction of the mean squared pressure at reference point (x=2.1m, y=1m), The secondary source and the reference sensor at the bogie-shroud; The secondary source and the reference sensor at the barrier

Figure 2 shows the results of the measurements at the reference point (x=2.1m, y=1m). At the other reference points we found comparable results, only the lower reference sensor showed a degradation through the active system The results show an advantage of the secondary source placed on the bogie-shroud.

References

[1] P.A.Nelson, S.J.Elliot, Active Control of Sound, Academic Press, Academic Press,1992